Quantum-Inspired Algorithm For Wireless Communications

RUTGERS
WINLAB | Wireless Information Network Laboratory

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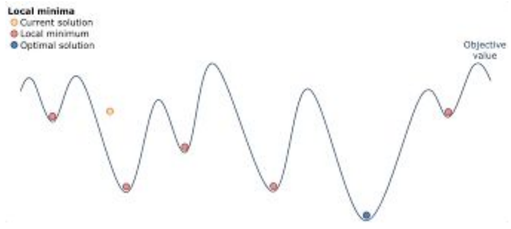
Motivation

As the number of wireless devices and demand for speed and low latency increase, current methods of wireless communication will soon no longer be sufficient. We propose two new methods to help deal with this.

Objective

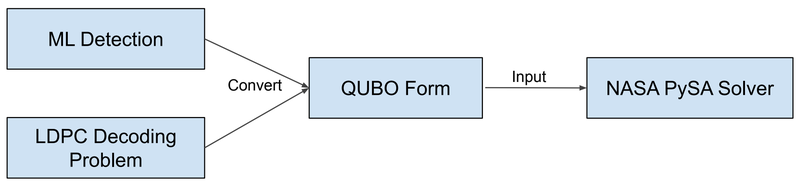
- Probabilistic metaheuristic: Simulated Annealing
- Think: Ball rolling down a hill



We use a quadratic unconstrained binary optimization function to mimic this energy problem
The algorithm we intend to implement randomly jumps to different states accepting both better and worse solutions based on a probability function that depends on temperature.

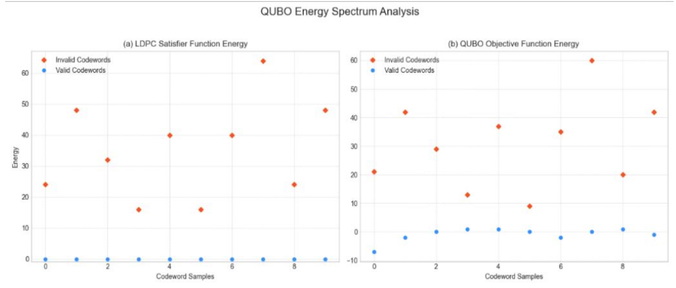
Designs

Isoenergetic Cluster Move (ICM): Works by running two replicas of the system and identifying clusters of variables where the replicas differ and then flipping the clusters simultaneously in both replicas in a way that preserves the total energy of the system.
Integer Reformulation: Used to lower complexity. Simulated annealing becomes difficult when working with a higher modulation. Higher modulation requires more binary variables to represent a value compared to a single integer variable.
Low Density Parity Check (LDPC): Used widely used in WiFi, satellite communications, and data storage systems. While they have exceptional abilities, their decoding precess is very computationally expensive.

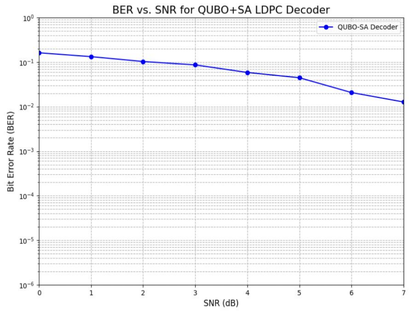


Results

- SNR of 5 dB was used for this plot, which is lower than real world scenarios

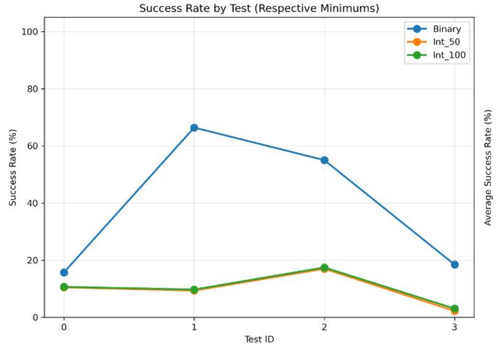


- Valid codewords have energy zero in LDPC Function Correct codeword is much lower than all other solutions

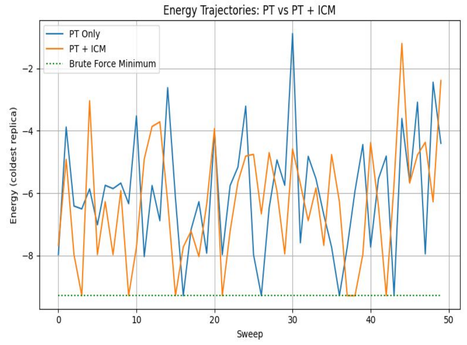


- The BER changes as SNR increases
While this is expected, we expect a greater fall off

- We tested 4 real world problem and compared them to their original binary version. Here are the results.



- To the right are the results of PT vs PT+ICM(Parallel Tempering on top of Isoenergetic Cluster Move algorithm) converging to be the best possible energy



Conclusions

- LDPC decryption consistently works with under 20 bit messages (with both added 0.05 error rate and noise added to transmission)
- Eventual Goal → IEEE standard for Wi-Fi communication (650 - 2000 bits)
- Isoenergetic Cluster Move Algorithm reached the best energy more consistently and with fewer sweeps than PT alone.

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=== PT vs PT+ICM Summary ===
Metric                          PT Only         PT+ICM
Best Energy                     -123.82459      -123.82459
Samples Reaching Best (%)       34.0            87.0
Avg Sweeps to Best              32.18           11.34
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- Integer reformulation proved to be feasible
  Average runtime for 50 sweeps(us): ~4397
  Average runtime for 100 sweeps(us): ~7844
- Future Work
  - Look at the formulation of LDPC code
  - Assure that we have an ideal problem
  - Look at BER vs SNR Performance
  - Reduce runtime overhead and optimize cluster formation.
  - Apply the method to real-world optimization tasks.
  - Improve the likelihood of convergence
  - Explore methods to reduce the run time

Goal

Our goal as a team is to accomplish a form of quantum wireless communication. With this project, we propose an alternative form of decoding that is physics based, and works quicker and with less computational resources needed

References

References

Kasi, S., & Jamieson, K. (2020). Towards quantum belief propagation for LDPC decoding in wireless networks. *Proceedings of the 28th Annual International Conference on Mobile Computing and Networking*, 1–14. https://doi.org/10.1145/3372224.3419207

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